Progress and challenges in EUVL mask repairs

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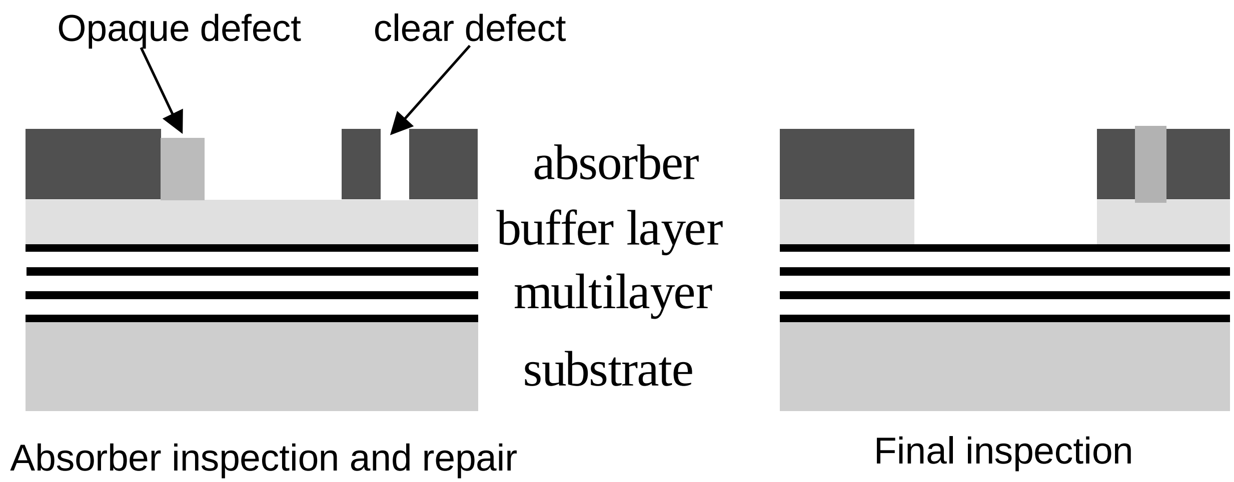
- NGL mask defect repair becomes increasingly important due to the complexity of NGL mask.
- EUV mask repair must not damage the ML.
- Current FIB capabilities are assessed. Key improvements are needed to meet 70nm repair requirements:
  - Imaging resolution at low kV
  - Etch selectivity
  - Edge placement precision

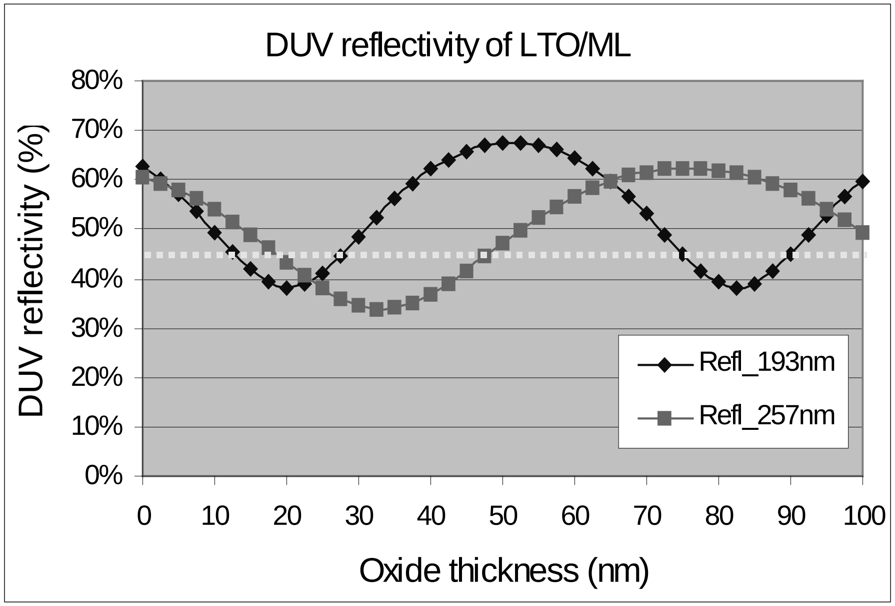
EUV mask architecture affects repair requirements



- Absorber layer (AL): Absorbs EUV, appears dark under DUV inspection
  - Baseline process uses TiN as absorber material
  - Cr and TaN are two current candidates under evaluation
- Buffer layer (BL): Provides etch stop and repair buffer to protect the ML
  - BL must be thick enough to stop metal etch during patterning
  - BL thickness must be optimized for inspection contrast
  - Thinner BL is preferred to limit overall absorber stack height for better lithography imaging performance

Buffer layer thickness optimized for inspection

- Conventional optical mask inspection will be used for EUV mask inspection
  - KLA-Tencor inspection tool requires ~60% contrast of AL vs. BL/ML
    - - Low absorber reflectivity is desired, ~10% is achievable.
    - - 50-80nm BL thickness is opted for DUV inspection



- A FIB repair process must work for the inspection-set BL thickness
- An ideal repair would be one that requires no BL (then inspection can be performed after BL etch)

EUV mask repair requirements

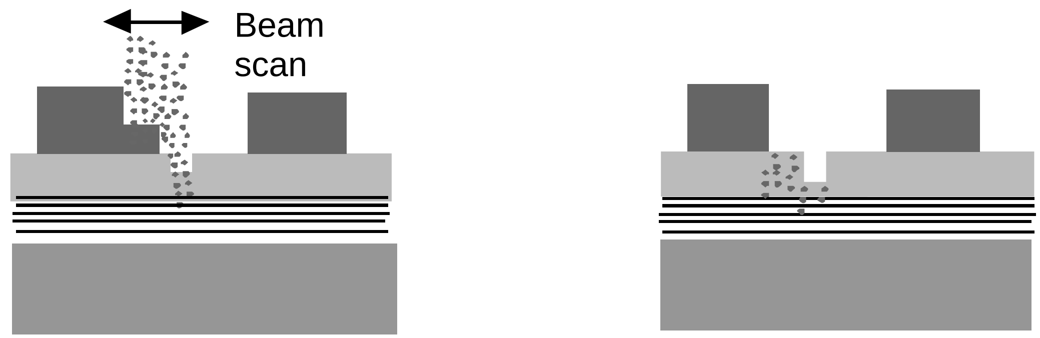
- 70nm mask specifications from ITRS'99:

Nominal wafer feature size/half pitch (nm)	70
Min. gate size on wafer (nm)	45
Min. space on mask (nm)	280
Min. line width on mask (nm)	180
Min. printable defect size on mask (nm)	55

Repair requirements	Spec	Key FIB attributes	Gap summary
1) General			
Limit ML damage (EUV refl. loss)	< 5%	kV, etch selectivity	Marginal
Resolve min. defect (nm)	55	Imaging resolution	Not OK
Edge placement precision (3σ, nm)	35	Imaging resolution, system stability	Marginal
2) Opaque defect repair			
Remove min. opaque defect (nm)	55	Etch resolution	Marginal
Confine etch within min. space (nm)	280	Min. 'effective' beam size	OK
GAE etch selectivity of absorber vs. BL	~2:1	GAE chemistry	Not OK
3) Clear defect repair			
Repair min. clear defect (nm)	55	Deposition and etch resolution	Marginal
Confine deposition within min. line (nm)	180	Min. 'effective' beam size	OK
Repair durability	Stable	Deposited material	Under eval.

EUV mask repair: limit ML damage

- ML damage during imaging and repair (over-scan) is caused by:
  - Ga ion implant into the ML
  - Buffer layer loss



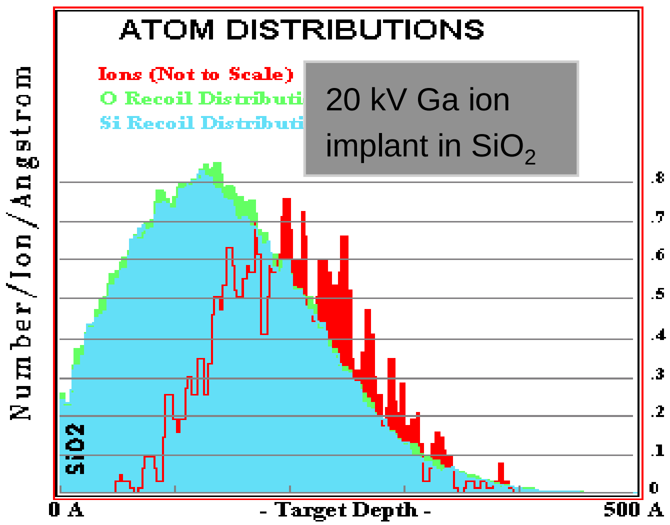
During repair After repair

- Buffer layer must stop Ga ions: BL loss + ion implant < BL thickness
  - Low kV ⇒ low ion penetration
    - Damage to Rp+2ΔRp
  - Higher selectivity ⇒ low BL loss: $S = t_{AL} / (t_{BL} - (Rp+2\Delta Rp))$
    - S > 2:1 for 50nm AL/50nm BL @20kV

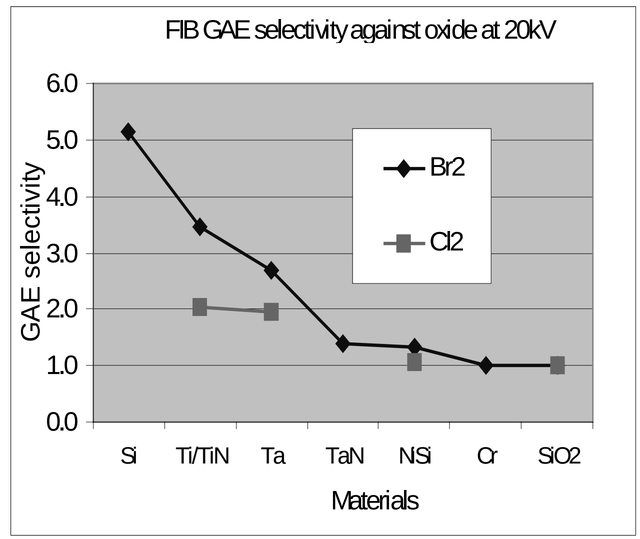
Required buffer layer thickness and etch selectivity

Ga implant in SiO_2 (Distances in nm)			
	30 kV	**20 kV**	**10 kV**
Projected range, Rp	25.6	19.1	11.9
Range straggle, ΔRp	7.5	5.8	3.9
Rp+2ΔRp	40.6	30.7	19.7
GAE selectivity (50nm AL/50nm BL)	5:1	2.5:1	1.7:1

Ion projected range from TRIM* calculation

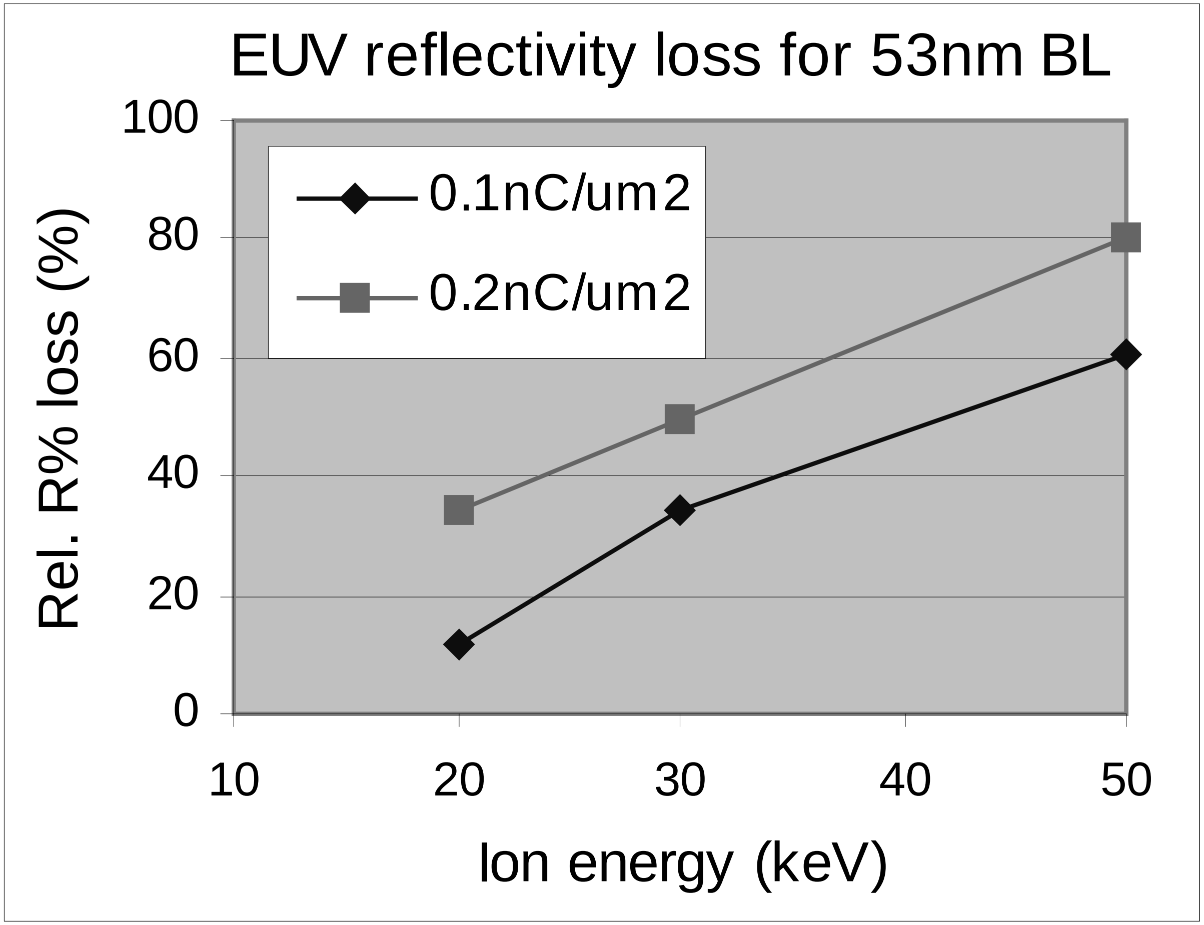


Etch selectivity of absorber vs. SiO_2 BL



* IBM

Measured relative EUV reflectivity loss

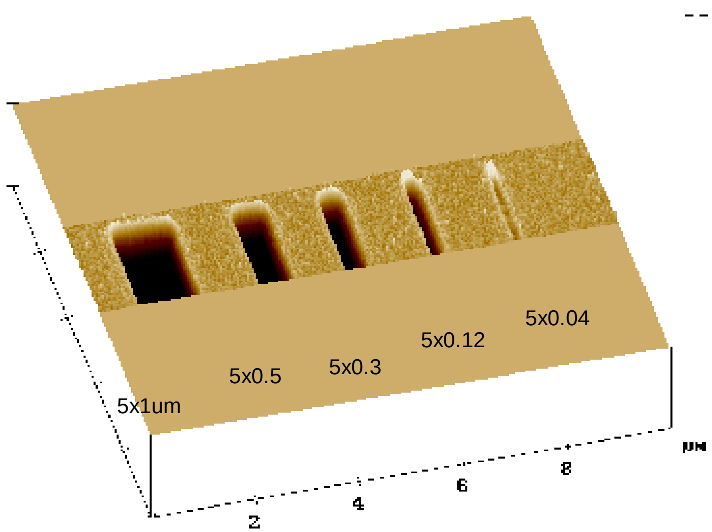


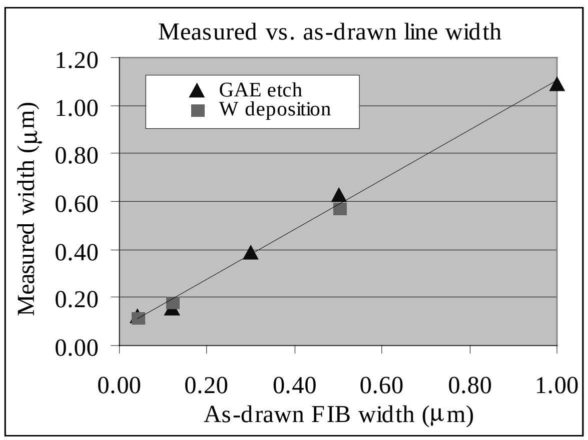
- Lower kV allows repair with higher ion dose

Repair resolution: Minimum 'effective' beam size

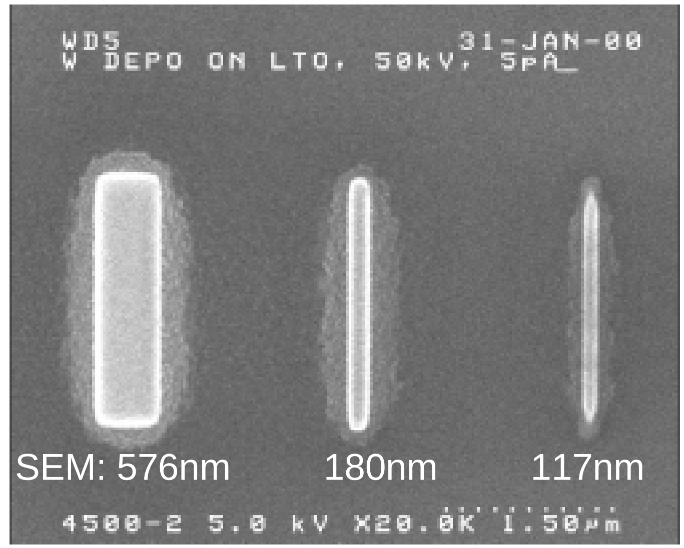
- Minimum 'effective' beam size determines the min. repairable space/line

GAE etch (opaque defect repair)





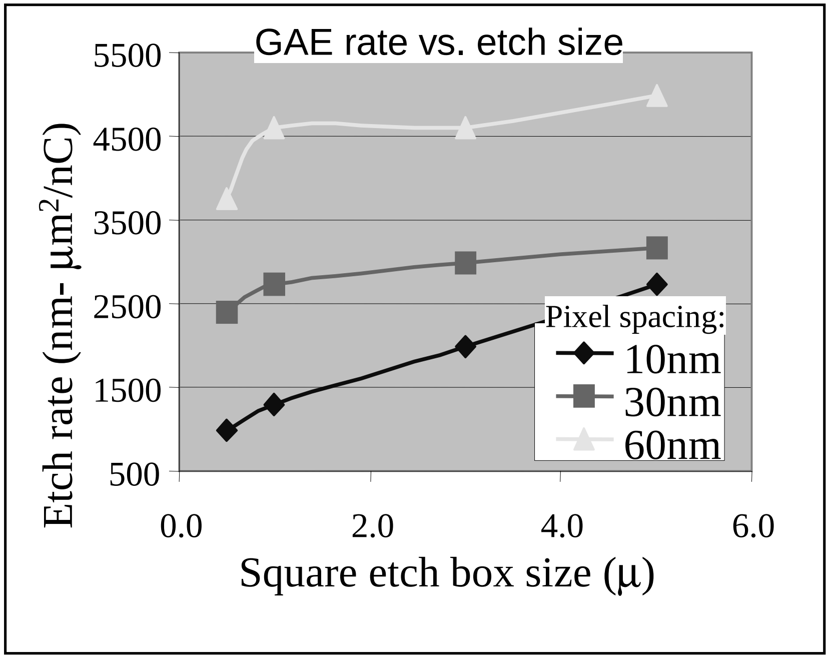
W deposition (clear defect repair)



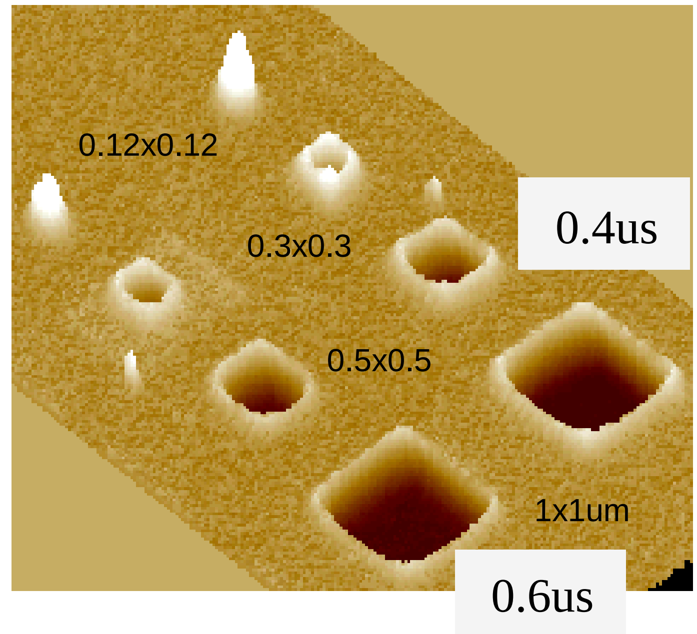
- Minimum size is ~120nm for both etch and deposition
- Meet min. space requirement, but
  - Need over-scan for opaque defect repair
  - Need post-deposition trim for clear defect repair

Opaque defect repair: GAE etch optimization

- Improve small area etch rate with large pixel spacing



- Reduce re-deposition with longer dwell time

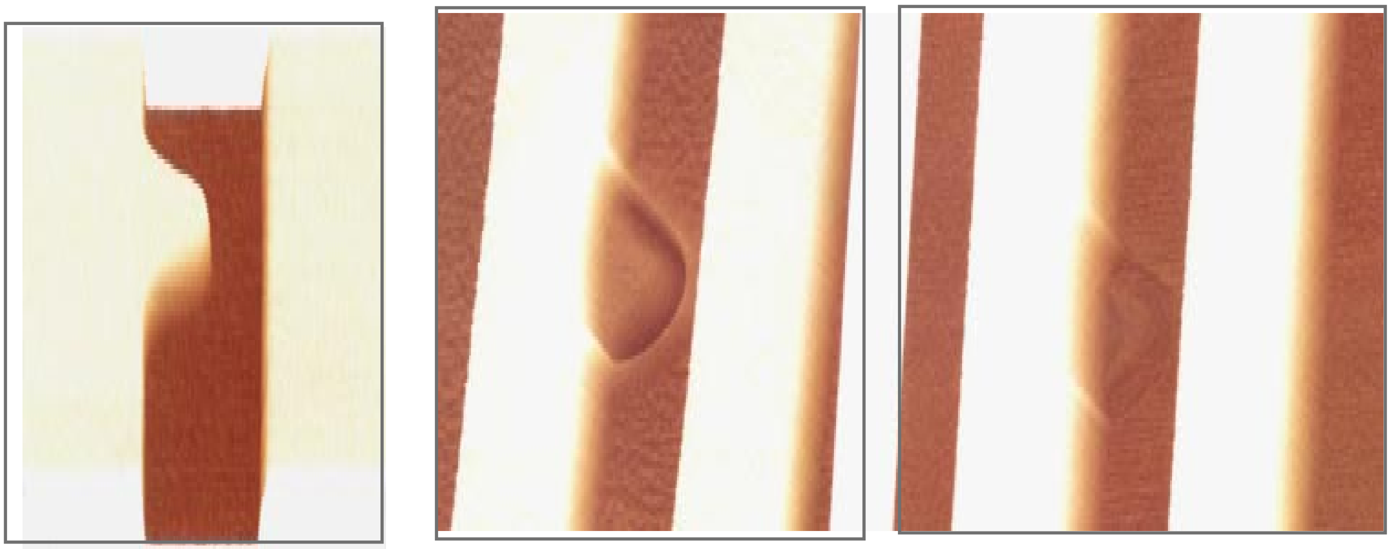


- Issues in small area etch:
  - Deposition from contamination and etch by-product (need clean system)
  - Need to over-scan repair area

Opaque defect repair process

- AFM metrology is needed to qualify the repair:

<u>1µm L/S with programmed defects (10X mask)</u>



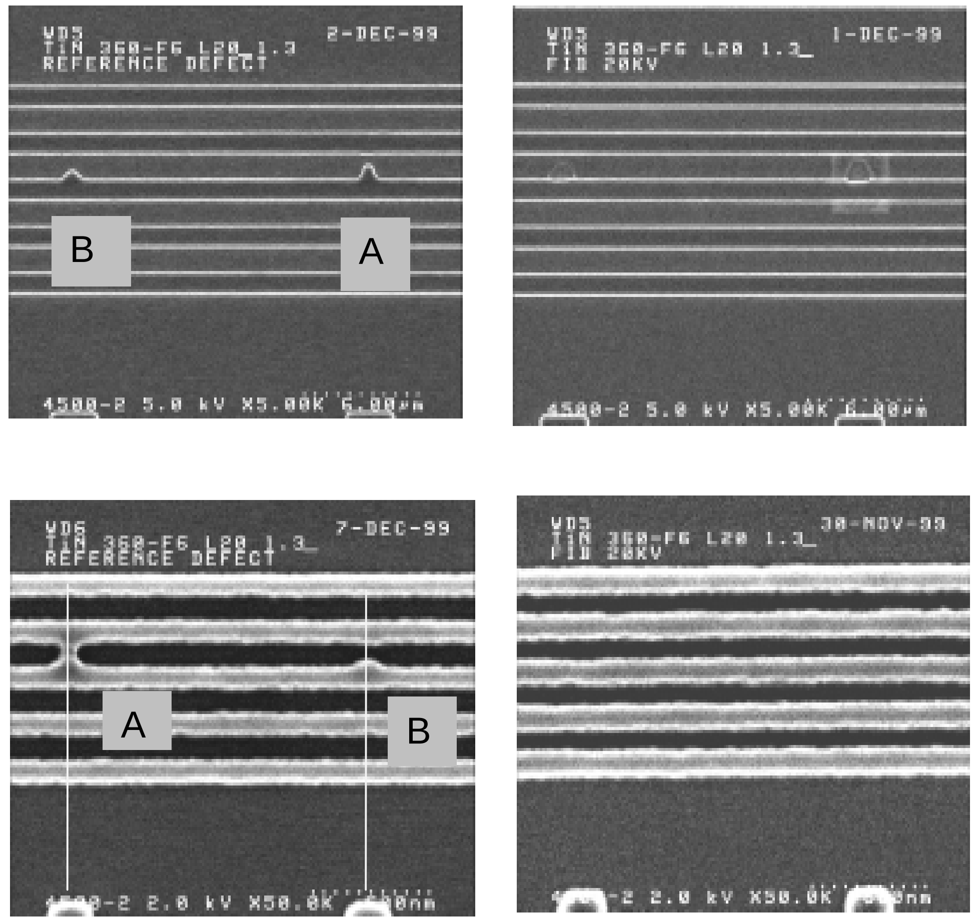
Before repair   After repair   After BL etch

Opaque defect repair print test

- 10X EUV print results of 100nm L/S demonstrated successful repair

Mask

Wafer

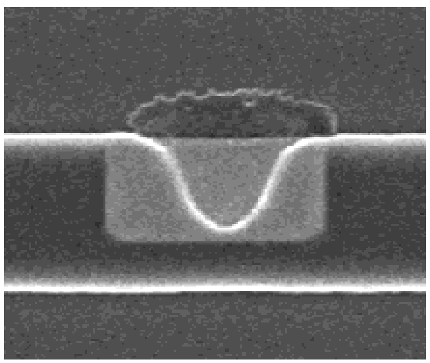


Before repair   After repair at 20kV

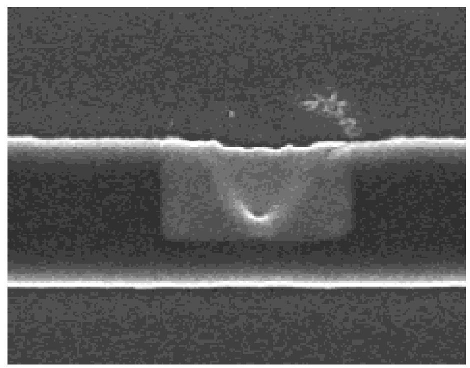
Clear defect repair process

- Ion-assisted W deposition is used for clear defect repair:
  - $W(CO)_6$ precursor is used.
  - Deposition at either 30kV or 50kV

SEM images of 1µm lines

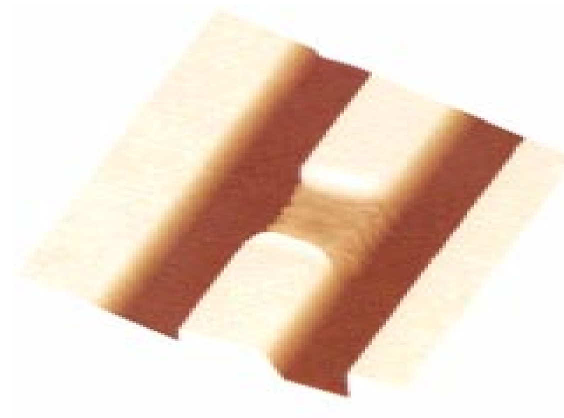


After W deposition



After GAE trim

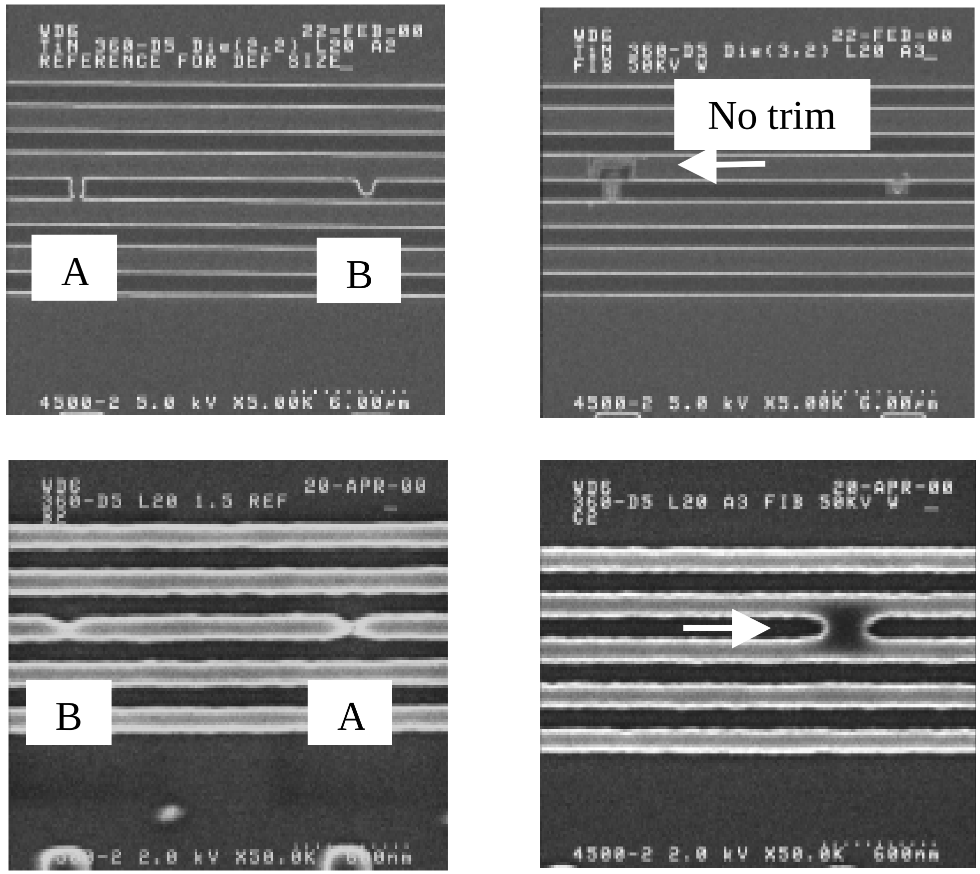
AFM image



- Any ML damage is hidden underneath the AL material
- Issue: Large deposition size and over-spray
- Requires a trim process following the deposition:
  - Eliminate the over-spray
  - Reduce repair size

Clear defect repair print test

- 10X EUV print results of 100nm L/S demonstrated successful repair

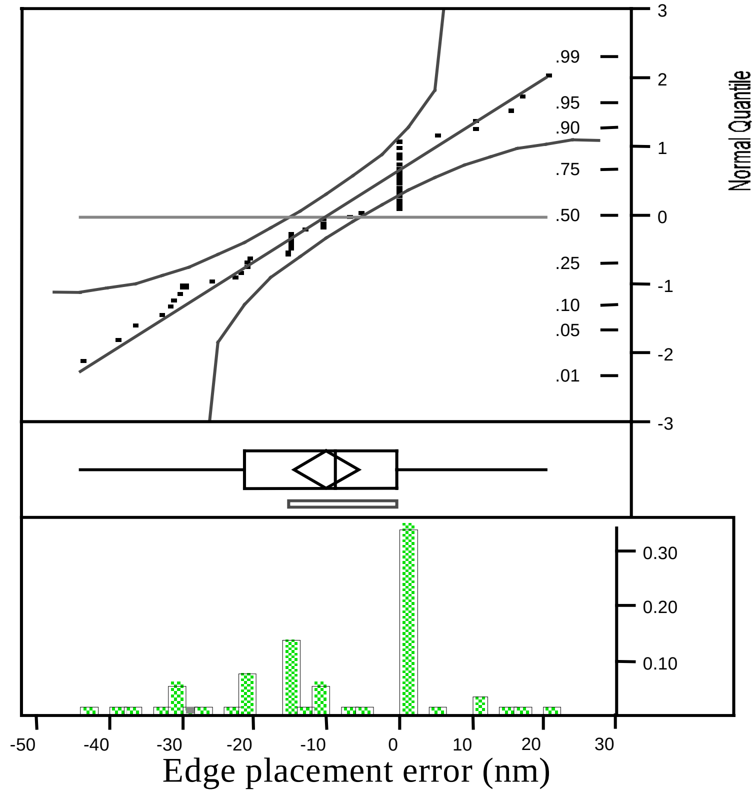


Before repair   After repair

- Repair is successful with post-deposition trim

Edge placement precision

- Probability plot of 30 repair measurements:



- ~ 45nm (3σ) EPP for both opaque and clear defect repair.
  - Future improvement is expected to meet the requirement.

Summary

- Opaque defect repair process developed:
  - Resolution: Meets the min, space (280nm) requirement
  - ML damage: Need low kV and high selectivity
  - Selectivity: Need better etch chemistry with higher selectivity
  - EPP: nearly meets the 35nm (3σ) requirement
- Clear defect repair process developed:
  - Resolution: Not meet requirement, need post-deposition trim
  - EPP: Nearly meets the requirement
  - ML damage: Less a concern
- The needs for future FIB research and development are identified to meet the mask scaling requirements:
  - Higher resolution at lower kV
  - High selectivity etch chemistries
  - Better edge placement

Future directions

- Mask repair technology must keep pace with lithography scaling.
- It requires high resolution FIB at low kV to resolve <55nm defects:
  - ML damage limits FIB to low kV
  - Small defect requires improved imaging resolution
- Shorter EUV absorber stacks maybe required in the future:
  - This requires thinner buffer layer
  - Need high etch selectivity and even lower kV FIB
  - Explore other types of ion sources that have less ML damage
- An ideal repair is one without the need for a buffer layer
  - Need non-damage repair process
  - Electron beam based processes may hold the promise for damage-free repair